Basis for Waves Data Rates

Survey:

Objective 2a (and others) require spectra and propagation properties at 6 second cadence. Hence, the Waves survey rate acquires such information at 20 log-spaced frequencies per decade from 10 Hz to 12 kHz once per 6 seconds (along with spectral information up to 400 kHz so as to be able to determine the electron density at the same cadence). This mode provides useful information on EMIC waves and plasmaspheric hiss. However, chorus has temporal structures of order 30 msec, hence, the determination of propagation characteristics (other than the spectrum) on longer time scales have no physical significance. Therefore, we have added a very low duty cycle of burst-mode data (simultaneous 6-channel waveforms for 20 seconds per hour, on average, equaling a duty cycle of 0.6%) to enable the determination of propagation properties of chorus, which requires temporal resolutions of order 30 msec on a low duty cycle basis to the survey data rate.

High Rate:

Objective 1.1a requires 3d wave fields measured at as high a temporal resolution as possible, hence, we have increased the survey rate by a factor of 6 for a basic cadence of 1 second, presumably for use during relativistic electron events or other intervals of interest. Accordingly, we also increased the duty cycle for chorus wave properties by a factor of 6, to 120 seconds/hour or a duty cycle of 3.3%.

However, this 'standalone high rate' mode does not allow for intensive studies of the propagation characteristics of chorus, only very brief, widely spaced snapshots of these. We have estimated very roughly that the RBSP trajectory will be close to the chorus source region (thought to be on the order of 2500 km from the magnetic equator) for approximately 25% of the time the spacecraft are beyond the plasmapause, or, a few hours per orbit. From this, we conclude that it is important to have the capability to acquire at least 30 minutes of nearly continuous burst mode data to enable the study of more than just tiny snippets of emissions widely spaced in time. Having such an opportunity once per orbit, on average, would enable the study of the chorus source region and different L values on successive orbits and to study the evolution of the source region in local time as the orbit evolves. Adding this 30-minutes of burst mode data to the 'standalone high rate' mode led us to the high rate mode, since we were forced to include any burst mode data to this mode (no burst mode data could be considered beyond the high rate).

Flexibility:

Part of this exercise, we feel, is making sure everyone fully understands the need and utility of Waves burst mode data. If only spectral information were required of Waves, then the strawman payload would have included only one electric and one magnetic sensor and the data volume would have been significantly smaller. However, the GMDT recognized the need to understand the propagation characteristics of the waves interacting with radiation belt particles and included 3 magnetic and 2 electric sensors for the instrument, assuming that the third electric component

could be estimated. Given a third electric field sensor, it only make sense to include measurements from it, as well. The only way to determine wave normal angles, the Poynting flux, and polarization of waves, such as whistler mode chorus, is to work with the full set of wave components. We do plan to have onboard algorithms to perform these computations onboard, but, you heard John Wygant express doubt as to how effective such onboard algorithms can be. We, too, are very concerned about the efficacy of such algorithms, although we believe that they will be useful under a majority of conditions. To verify this, however, it is essential to return raw waveforms to the ground to validate the onboard algorithms and to use alternate analyses to ensure the onboard algorithms are working correctly and, perhaps more importantly, to understand under which conditions the onboard algorithms should not be trusted. We anticipate that with such a validation process, we will be able to rely more on the onboard algorithms later in the mission. Even so, returning spectra and wave propagation properties at 30 msec resolution for chorus is still very data volume intensive.

We cannot say that the high rate requested is the minimum required to do the RBSP science. In fact, we proposed an average rate of about 5 kbps as our understanding of the GMDT's intention for the Waves investigation and that this would suffice as a minimal investigation and would consider this a performance floor. In fact, the proposed rate is very similar to the suggested survey rate currently being requested. However, significantly more burst mode data is required to do a good job of understanding the propagation characteristics, primarily of chorus.

Further, we believe EMFISIS and the RBSP spacecraft will have varying data volume capabilities over time. We understand that it is likely not possible to devote of order 100 kbps to Waves continuously all the time. The high rate requested is actually on the low side given the science requirements, many of which rely on understanding the propagation characteristics of chorus. But, we are willing to negotiate a rate that is reasonable and realistic, with the anticipation that high rates may be available during some portions of the mission where we might carry out chorus-intensive studies that are not always affordable.

Finally, in reading the Waves measurement requirements for the 8 AO objectives, it is clear that there is a lack of specificity and detail that might make the requested data rates more understandable. We're willing to work on the requirements to address this. However, simply stating a requirement of measuring the wave propagation characteristics of chorus very quickly leads to the very high data rates requested because of the requirement for waveform data from 6 sensors and very high time resolutions dictated by the nature of chorus. It really comes down to a question of duty cycle. For survey, this duty cycle is 0.6% and even for the 'standalone high rate it is only 3.3%. Adding a half-hour per orbit of nearly continuous burst mode data specifically to study chorus is, in itself, only 5% duty cycle and when added to the 'standalone' burst data the total is still well short of 10%. We cannot in any way imagine that studying the wave properties of an emission as important to understanding the radiation belts as chorus at a duty cycle of less than 10% is excessive, in anyone's estimation.

Waves Measurement Requirements per AO Objectives: Drivers on Waves Data Rates

1.1.a-2
3-dimensional electromagnetic wave fields must be measured at frequencies ranging from TBD to TBD. Measurements must enable identification of wave populations that interact with radiation belt electrons including VLF Hiss, whistler chorus, and EMIC waves. Statistical spatial distributions of those waves must be determined. Time resolution for full spectra must be as high as practical and no greater than one spin.

1.1.a-3
same as 1.1a-2 plus waveform, spectral, and frequency resolution that enable determination of critical characteristics such as wave normal angle (k)

1.1.d-1
Measure wave fields to determine if interplanetary shocks produce or alter other wave populations in the inner magnetosphere.

2a-1
3D vector E and B frm 10 hz to 12 kHz. Routine spectra, wave normal, Poynting flux at 6 s cadence. Chours with 30 ms resolution.

2a-2
3D vector E and B frm 10 hz to 12 kHz. Routine spectra, wave normal, Poynting flux at 6 s cadence. Chours with 30 ms resolution.

3c-3
Survey wave properties in the range from 10 Hz to 12 kHz, including spectrum, polarization, propagation properties. Additionally, provide occasional high temporal resolution for bursty emissions such as chorus.

3e-1,2,3,4
Survey wave properties in the range from 10 Hz to 12 kHz, including spectrum, polarization, propagation properties. Additionally, provide occasional high temporal resolution for bursty emissions such as chorus.

4Q-1b
Measure the 3 D wave magnetic field variation over the amplitude range from TBD nT to 4 nT over the frequency range between 100 Hz to 10 kHz. Measure wave electric fields over same frequency intervals. Wave normal direction from minimum variance. For electrostatic waves need 3-d electric fields for k wave normal. Need phase velocity, coherence. Spatial scale sizes interferometrically for 10 m to 10 km. timing wth phase velocities utp 1000 km/s. Burst wave form for assessing above properties with wave form information.

4Q-1c,d
Measure background density by determining frequency of plasma line using E field spectra from 10 kHz to 500 kHz (1-2500 cm-3) Sensitivity TBD at a cadence of once per minute. INCLUDE MEASUREMENTS FROM ABOVE. Requires intervals of burst wave form data.

4Q-2c
same as 4Q-1

4Q-5b
same as 4Q-1

5c-2
Survey E and B wave properties in the range from 10 Hz to 12 kHz, including spectrum, polarization, propagation properties, 6 s resolution. Additionally, provide occasional high temporal resolution for bursty emissions such as chorus.

5d-2
same as 5c-2

5e-2
same as 5c-2

6c-1
Wave data (TBD specification); 30msec resolution for Chorus

7b-1,3
Plasma frequency meausrement

7f-3,4
Plasma frequency meausrement
Need swept frequency receiver frequency range up to 400 kHz (1600/cc)

8b-2
3D wave electric field:300 mv/m to 0.01mV/m @1 Khz, TBD range > 1 kHz; 3D wave magnetic field TBD range over 10 Hz to 10 kHz . [The full range of frequencies and amplitudes effecting particle dynamics.] VLF wave data could be a critical model driving parameter.

8c
same as 8b-2

8d
same as 8b-2

Driving Requirements

(Note: where requirement appears in multiple objectives, only one objective is cited.)

Number of components: 3 E, 3 B (Objective 2a)

Frequency Range (EMIC, VLF Hiss, Chorus): 10 Hz to 12 kHz (Objective 2a)

Temporal resolution for spectra: must be as high as practical and no greater than one spin (Objective 1-1a-2) (interpret as 1 to 12 seconds)

Spectral resolution (EMIC, VLF hiss, chorus): 20 channels/decade (delta-f/f ~12%) (Assumed, from 1-1a-3)

Temporal resolution for chorus spectrum, wave normal, Poynting flux, etc.: 30 msec (Objective 2a) (this drives the requirement for extended burst mode data)

Frequency Range (for density determination): 10 kHz - 500 kHz (Objective 4Q-1c)

Spectral resolution (for density determination): 50 channels/decade (delta-f/f ~5%) provides ~10% density resolution (assumed requirement)

EMFISIS/Waves Data Rates

Waves has a highly flexible capability to produce rates from a few kbps for survey to literally ~1 Mbps for burst rate.

I. Survey Data:

Some Waves burst data are required at a low duty cycle to validate onboard processing of spectral matrices and wave propagation properties. Therefore, even the Waves survey data require some of this instrument-internal burst data. We have scaled this to be approximately that which was included in the EMFISIS proposal, but can be varied, within bounds, if needed.

Component	Rate (bps)
HFR: 10 kHz - 1 MHz, 50 channels/decade 1/6s (10% density resolution)	200
Spectral properties at 1/6s rate, 66 log-spaced channels	682
Waves-internal burst (6-channel waveforms at 20 seconds/hour, average)	<u>5825</u>
Total Survey Rate	6707

Corresponds to 217 Mbits/orbit or 580 Mbits/day

II. High Rate

The Waves High Rate mode averages **9168 Mbits/day**, made up from the sum of the standalone high rate data identified in Section A, below plus one burst intensive activity per orbit, or about 3 per day, as detailed in Section B, below.

A. Standalone High Rate:

We interpret High Rate data as an elevated rate to support long-duration events (few days) such as storm periods. For this, we have assumed a higher cadence for spectral information and a somewhat elevated duty cycle for burst data. Note that this mode does not support intensive burst mode data (see section B, below, or it's alternative, section C). Section D sums the rates from the standalone high rate mode (this section) and one Burst intensive event per orbit (Section B) to arrive at an all-inclusive High Rate daily-averaged rate.

Component	Rate (bps)
HFR: 10 kHz - 1 MHz, 50 channels/decade 1/s (10% density resolution)	1200
Spectral properties at 1/s rate, 66 log-spaced channels	4092
Waves-internal burst (6-channel waveforms at 120 seconds/hour, average)	<u>34952</u>
Total	40244

Corresponds to 1304 Mbits/orbit or 3477 Mbits/day

B. Burst Intensive Rate:

For shorter 'campaign-like' time periods, such as an intensive study of near-equatorial chorus emissions, we suggest a 'burst-intensive' mode which covers a typical interval of ~30 minutes. It should be noted that the total data volume in such an activity exceeds the EMFISIS burst mode buffer and would require a high rate data line to the solid state recorder supporting slightly more than 1 Mbps. The 50 Mbyte EMFISIS burst mode buffer would be filled in just over 6 minutes.

Component	Rate (bps)
HFR: 10 kHz - 1 MHz, 50 channels/decade 1/s (10% density resolution)	1200
Spectral properties at 1/1s rate, 66 log-spaced channels	4092
Waves-internal burst (6-channel waveforms)	<u>1048575</u>
Total	1053867

Corresponds to 1897 Mbits **for a 30-minute interval**

C. Burst Intensive/Alternate:

An alternate mode might be envisioned for a sizeable fraction of an orbit, e.g. from the nominal plasmapause to apoapsis and perhaps more. Here, we assume that we have faith in our onboard wave-property analysis and use this for high temporal resolutions and high duty cycle for a several-hour period. Again, this would be something that might be designed to do a more comprehensive study of chorus from the plasmapause to apoapsis.

Component	Rate (bps)
HFR: 10 kHz - 1 MHz, 50 channels/decade 1/6s (10% density resolution)	200
Spectral properties at 1/6s rate, 66 log-spaced channels	682
Spectral properties at 1/30ms rate, 33 channels around fce/2	<u>62500</u>
Total	63382

Corresponds to 913 Mbits/orbit + survey **assuming 4 hours/orbit**

D. High Rate including Burst Intensive Data

This rate combines the standalone High Rate Mode with Burst Intensive periods at the rate of one 30-minute interval per orbit (or ~ 90 minutes per day).

The daily rate for standalone high rate is 3477 Mbits/day. Adding to this three 30-minute Burst Intensive periods at 1897 Mbits, each, the total all-inclusive Waves High Rate amounts to **9168 Mbits/day**.